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COMPENSATION ON DEPLOYMENT OF AIRBRAKES AND LESSONS LEARNED FROM LCA FLIGHTS

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ABSTRACT: The airbrakes are part of high performance aircraft and its location is arrived at based on wind tunnel experiments and in actual practice it is a compromise between the 'desired' location, which gives the least pitching moment and the best 'available' location on aircraft 'near to the desired one'. The requirement is such that on deployment of airbrakes the drag should increase without any decrease in lift. If the airbrakes are not installed at the 'desired locations', aircraft starts pitching up and 'pitch up' increases with the airspeed. The 'ideal' requirement is that when airbrakes are deployed pilot should be able to concentrate on his mission without making an effort towards controlling the pitching moment. Thus, it is necessary to automatically compensate the pitch up tendency of the aircraft on deployment of airbrakes, and can be implemented in the Digital Flight Control Computer (DFCC) software.

This paper addresses the design of the automatic pitching moment compensation loop on deployment of airbrakes. The pitching moment compensation is implemented as a feed forward loop and hence, can be designed independent of the feedback control laws.

It is very important to model all the nonlinearities related to the airbrakes very accurately, since the pitching moment compensation loop is in the feed forward path. Therefore, any delays or nonlinearities affect the performance significantly. This paper discusses the lessons learned from the LCA programme.

1. INTRODUCTION

LCA is a single engine tail-less delta wing supersonic fighter aircraft, which is designed to be aerodynamically unstable in the longitudinal axis. LCA is stabilized artificially and the desired performance is achieved over the entire flight envelope using a quad redundant full authority digital Fly-By-Wire (FBW) Flight Control System (FCS). The control laws resident in the sophisticated electronic FBW-FCS in addition to guaranteeing stability optimize the aircraft performance and piloted handling qualities over the entire flight envelope for all aircraft external store configurations. An overview of the design, development and testing of the flight control laws for the LCA is given in [1].

Aerodynamic brakes (airbrakes) are secondary surfaces, which develop a large separation wake and increase the pressure drag. The requirement is such that on deployment of airbrakes the drag should increase without significant decrease in lift as they are used to slow down the airspeed quickly while approaching for a landing or during a dive. For LCA three airbrake locations were studied (Fig. 1) and the rear location was selected based on space constraints and also because the overall performance of the airbrakes was better. However, this location leads to significant pitch-up and reduction in directional stability at higher airspeeds / Mach numbers [2]. The 'ideal' requirement is that on deployment of airbrakes there should be minimal change in the pitching moment with required increase in drag so as to enable the pilot to concentrate on the mission. On Tejas due to the rear location, as the airbrakes are extended at higher Mach Nos, the flow over the vertical fin is disturbed leading to a significant reduction in directional stability. To augment directional stability, the sideslip feedback loop gain is increased as a function of airbrake position.

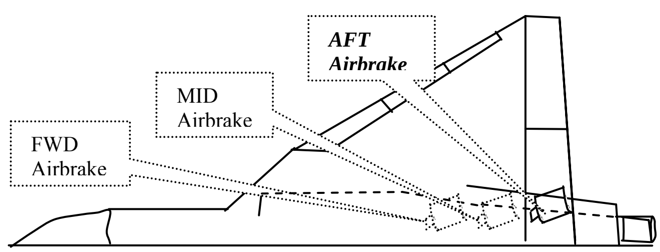

Fig.1. Assessment of Various Airbrake Locations in Wind Tunnel

This paper is divided into five sections. In the second section design of pitching moment compensation loop is presented. The third section discusses the lessons learnt from flight tests. Reduction in directional stability due to airbrakes operation and augmentation of directional stability are presented in the fourth section. The fifth section concludes the paper.

2. PITCHING MOMENT COMPENSATION

2.1 Methodology

Airbrakes on LCA can be positioned over a range of 0-60^0, at the rate of 30^0 / Sec from fully retracted to fully extended position. Left and Right airbrakes are synchronized by a hydraulic flow synchronizer valve which ensures symmetric extension and retraction.

The analysis given below shows that the design of the feed forward pitching moment compensation is independent of the stability augmentation feedback loops.

a) Open Loop: Airbrake compensation without feedback from pitch rate (q) and Normal acceleration (Nz) sensor to elevator input

In Fig. 2a, P_q and P_{Nz} are the transfer functions from elevator (δ_e), $P_q^{'}$ and $P_{Nz}^{'}$ are transfers function from airbrake (δ_{ab}) to q and Nz respectively.

$$\begin{bmatrix} q \\ Nz \end{bmatrix} = \begin{bmatrix} P_q \\ P_{Nz} \end{bmatrix} \delta_e + \begin{bmatrix} P_q^{'} \\ P_{Nz}^{'} \end{bmatrix} \delta_{ab} \tag{1}$$

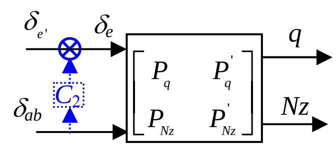

Fig.2a. Airbrake compensation for a plant without feedback controller

On deployment of airbrake there is a pitching moment generated. To nullify the effect of airbrake on pitch rate and normal acceleration, the transfer function block C_2 from δ_{ab} to δ_e shown as dotted in Fig. 1 has to be designed. For this purpose, substitute $\begin{bmatrix} q \\ Nz \end{bmatrix} = 0$ in (1) which leads to

$$\begin{bmatrix} P_q \\ P_{Nz} \end{bmatrix} \delta_e = -\begin{bmatrix} P_q^{'} \\ P_{Nz}^{'} \end{bmatrix} \delta_{ab} \tag{2}$$

For a typical fighter aircraft, frequency response of the ratio $\frac{P_q^{'}}{P_q}$ is approxmiately equal to $\frac{P_{Nz}^{'}}{P_{Nz}}$ upto 1Hz (it is within 1dB, see the next section) Thus,

$$C_2 = \frac{\delta_e}{\delta_{ab}} = -\frac{P_q^{'}}{P_q} = -\frac{P_{Nz}^{'}}{P_{Nz}} \quad (<1Hz) \tag{3}$$

Note that when there is no compensation, $\delta_e = \delta_{e'}$ otherwise $\delta_e = \delta_{e'} + C_2\delta_{ab}$.

b) **Closed Loop** Airbrake compensation for the plant with feedback from pitch rate and normal acceleration to elevator

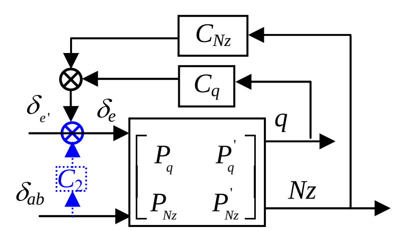

Fig.2b. Airbrake compensation for a plant with feedback controller

In Fig. 2b, C_q and C_{Nz} are the feedback controllers designed for the plant with pitch rate (q) and normal acceleration (Nz) as inputs. Now δ_e is

$$\delta_e = -\begin{bmatrix} C_q & C_{Nz} \end{bmatrix} \begin{bmatrix} q \\ Nz \end{bmatrix} + \delta_{e'} \tag{4}$$

From (1) and (4) we obtain

$$\begin{bmatrix} q \\ Nz \end{bmatrix} = \begin{bmatrix} 1+P_qC_q & P_qC_{Nz} \\ P_{Nz}C_q & 1+P_{Nz}C_{Nz} \end{bmatrix}^{-1} \begin{bmatrix} P_q \\ P_{Nz} \end{bmatrix} \delta_{e'} + \begin{bmatrix} 1+P_qC_q & P_qC_{Nz} \\ P_{Nz}C_q & 1+P_{Nz}C_{Nz} \end{bmatrix}^{-1} \begin{bmatrix} P_q^{'} \\ P_{Nz}^{'} \end{bmatrix} \delta_{ab}\,. \tag{5}$$

To nullify the effect of δ_{ab} on q and Nz we need to add the controller δ_{ab} to $\delta_{e'}$. If we substitute $\begin{bmatrix} q \\ Nz \end{bmatrix} = 0$ in (5), and multiply both sides with $\begin{bmatrix} 1+P_qC_q & P_qC_{Nz} \\ P_{Nz}C_q & 1+P_{Nz}C_{Nz} \end{bmatrix}$, we obtain (2) which were derived for the open loop plant without any feedback. Thus the design of airbrake compensation is independent of the stability augmentation control law.

2.2 Linear models

From the previous section it can be seen that pitching moment compensation command to the elevator due to airbrake deflection can be defined as the ratio of sensitivity of pitch rate to the airbrake and elevator deflection. The aircraft linear models for the longitudinal axis of the aircraft were generated for different positions of the airbrakes using Six-DoF simulation software. As the aircraft pitching moment behaviour varies with the operating flight condition, the linear models were generated at selected flight conditions to cover the entire operational flight envelope.

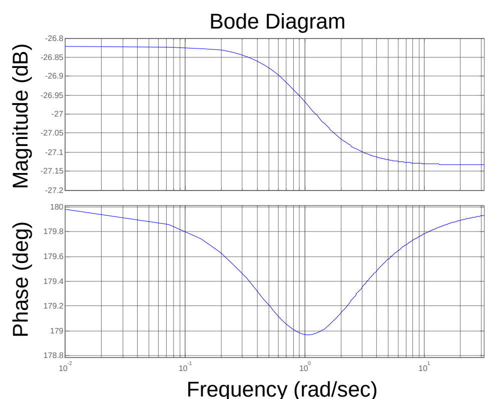

Fig. 3. Bode diagram of **(** $P_q^{'} / P_q$ **)**

2. 3 Evaluation of compensation scheme

The transfer functions P_q **and** $P_q^{'}$ were derived from the linear models at each flight condition for 0 , half and full airbrake deflections. The ratio of pitch rate sensitivity to airbrake deflection and elevon deflection was determined by calculating the steady state gain of the short period transfer function ratio ($P_q^{'} / P_q$). A Bode plot of ($P_q^{'} / P_q$) for a typical flight condition is shown in Fig. 3. It can be seen that the gain and phase are almost constant at low frequencies. Since the airbrake deployment is slow, dynamic compensation was not necessary and only static gain compensation was sufficient. This gain was found to vary with the aircraft mass configuration and operating flight conditon. It was also observed that the variation of the gain with aircraft mass configuration was not significant and hence the mean value of the gains were calculated for each flight condition. The average gain is scheduled with the flight condition to cover the full envelope.

It was observed that, the pitch rate sensitivity was a nonlinear function of the airbrakes position. Therefore a nonlinear function block was suitably designed to capture the nonlinearity of the pitching moment to airbrake deflection. The time constant of the leadlag fiter was tuned for minimising the net pitching moment. The compensation scheme is shown in Fig. 4.

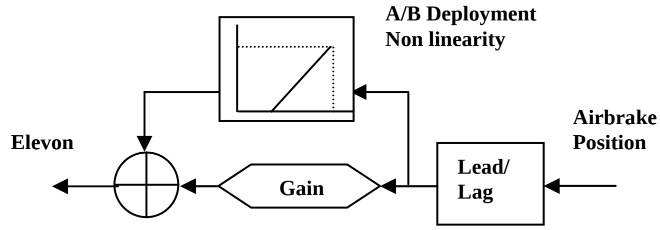

Fig. 4. Pitching Moment Compensation

3. LESSONS LEARNED

The pitching moment compensation loop incorporated into the flight control laws for deployment of airbrakes has been designed using the wind tunnel data generated for two positions of the airbrake (30 and 60 degrees), and the effectiveness of this loop was verified using piloted nonlinear simulation. However, during initial LCA flights when airbrakes were extended, the pilots reported that the pitching moment compensation, at higher dynamic pressures was not as effective as on the simulator. Therefore, it was necessary to establish the reason for the mismatch between flight and ground simulation. The reasons of mismatch could be either due to differences in the airbrake related aero data parameters used for designing the pitching moment compensation, or due to errors in the design of the pitching moment loop itself, or due to the combination of both.

In order to establish the reason for the mismatch between flight and simulation, dedicated LCA flights were carried out. In these flights, airbrakes were deployed without any stick movement, from 0^0 to approximately 30^0 with hands off stick. Aircraft was once again trimmed with the airbrakes at the middle position ($\approx 30^0$). Airbrakes were then extended from $\approx 30^0$ to 60^0 without any stick movement. Similarly, "hands off" airbrake extension was carried out from 0^0 to 60^0. This flight test data however, includes the effect of the pitching moment compensation loop. This flight test data was necessary to update the aero tables related to airbrake pitching moment. One way to estimate these derivatives (pitching moment due to airbrakes) is by perturbing the aerodynamic parameters in the nonlinear off-line simulation to match the flight test responses. The match with the flight-generated responses is obtained by varying the derivatives related to the airbrakes in the simulation model using optimization techniques.

However, the flight data response matches were still found to be unsatisfactory. Further study revealed the following three nonlinear elements in the airbrake position measurement that had not been taken into account during design of the pitching moment compensation loop. These were

1. Additional delay due to scheduling of various tasks across the minor frames in the DFCC
2. Errors in the LVDT scaling factor
3. Nonlinear Relation between the linear Airbrake actuator deflections in mm to the rotational deflection of the surface in deg.

The modeling of these three nonlinear blocks was carried out in the offline simulation software and the corresponding aero tables were also updated.

4. AUGMENTATION OF DIRECTIONAL STABILITY

Deployment of the airbrakes on LCA leads to a significant pitching moment and this also reduces the aircraft directional stability. The aerodynamic data shows the reduction in Cnβ on deployment of airbrakes especially in the transonic (0.9 to 1) Mach range. Therefore a study was carried out to analyze the effect of this reduction in Cnβ for pilot lateral stick inputs. The peak excursions of β with and without airbrake deployment were compared at different Mach numbers. In the aerodynamic data, the yawing moment produced due to airbrakes operation is given as an additional term and it is a function of Mach number and Angle of Attack. The variation of non-dimensional derivative - Cnβ as a function of Mach number with and without airbrake deployment is shown in the Fig. 5 for a typical 3 km altitude. It is observed from Fig. 5, that the reduction in Cnβ is maximum in the range of 0.9 to 1.0 Mach number. The sideslip excursions due to airbrake deployment at 0.5 M increases from 1.933 deg. to 3.059 deg. However, at 0.95 Mach the sideslip excursions are significantly higher with airbrake deployment (0.930 deg. to 4.113 deg.). To augment directional stability, the airdata scheduled sideslip feedback loop gain is increased as a function of airbrake position.

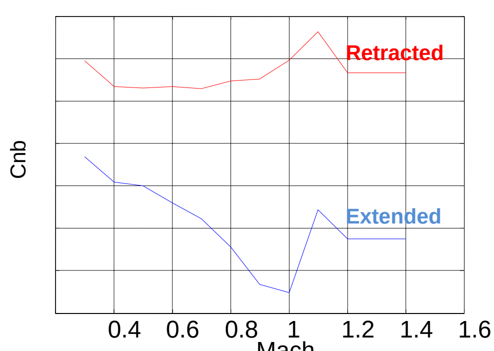

Fig. 5. Cnbeta as function of Mach (at 3 Km)

5. CONCLUSION

This paper gives an overview of the design, development and testing of an Airbrake Compensation Scheme for the TEJAS aircraft. Proper location of the airbrakes are extremely important even in modern aircraft like TEJAS which employ sophisticated electronic fly by wire flight control systems, as the pitching moment compensation can be done only using a feed forward loop. Even small errors in the estimation of the airbrake related stability and control derivatives, system nonlinearities etc., can result in significant residual moments on airbrake deployment which will not be acceptable to the pilot. As seen in the TEJAS programme correcting these deficiencies needs sufficient flight test data across the flight envelope which is a time consuming and costly process.

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